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ECONOMIC IMPACTS OF CLIMATE CHANGE ON URBAN WATER USE IN CALIFORNIA

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

The work described in this report was conducted under the Preliminary Economic Analyses of Climate Change Impacts and Adaption, and GHG Mitigation contract, contract number 500-02-004, work authorization MR-006, by the University of California, Berkeley.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

This report describes the California Climate Change Center's initial efforts to estimate both urban water demand from disaggregated, household level data, and the short- and long-term consumer surplus losses for urban water agencies in California. To create a baseline from which to estimate urban water demand, researchers at the Center collected data covering over 1.2 million California households, from 15 geographically representative water agencies around the state. The households are subject to a variety of rate structures. This data set is roughly one thousand times larger than the data sets utilized in the existing literature.

To estimate urban water demand, researchers at the Center performed an econometric analysis of the household water consumption data, controlling for climate variation, rate structures, and population and housing characteristics from the Census 2000 block group level. This report presents the results of the estimations for Los Angeles and the descriptive results for the City of Santa Rosa. The econometric work included both cross-sectional and time-series analysis as needed to define relationships between water supply reliability, price, and economic outcomes for these urban regions.

The Los Angeles results indicate that the short- and long-run demand is less price-elastic than suggested by previous studies. The Santa Rosa work also shows that within a single city, housing vintage effects household water consumption rates. Newer houses—controlling for climate, population characteristics, water price structures, and conservation measures—consume more water than older houses.

1. Introduction

The major pathway by which climate change will affect the California economy is through its impact on the California water system. Therefore, a major component of the research being conducted at the University of California, Berkeley, is an economic analysis of the California water system to assess the economic costs associated with changes in the reliability of supply for water users in various parts of the state.

In California, climate change is likely to severely exacerbate the existing mismatch between where and when rain falls and where and when people need to use water. To assess these impacts, the research team is conducting a broad suite of studies on various aspects on the California water system. The overall research involves six main components:

> (1) Measure the existing reliability (degree of certainty) of the water supply for various irrigation districts and urban water agencies around the state given their various sources of supply, and their water rights or water contract entitlements. To accomplish this task, researchers identify specific water users (agricultural and urban) who will be the focus of the study, and assemble a database of information on their water supply (e.g., contractual water entitlements, water rights, other sources of supply, within-district storage); their water demand (e.g., cropping pattern, population, number of industrial, commercial and residential customers etc); and the economic value of water to their customers (e.g., water costs and pricing, crop prices, other input prices, farmland values).
>
> (2) Conduct an econometric analysis based on cross-section and time-series data of the relationships between supply reliability and economic outcomes for irrigation districts in California, including agricultural practices, choice of crops, farm profit and land values. These relationships measure the economic consequences of differences in supply reliability, and will be used to develop economic loss functions for changes in agricultural water supply reliability.
>
> (3) Conduct an econometric analysis based on cross-section and time series data on urban water use for urban water agencies in California to estimate demand functions for water. The resulting short- and long-run price elasticities of demand will be used to develop short- and long-run loss functions for shortages in urban water supply in California. The demand elasticities with respect to conservation variables will be used to assess the future potential for reducing urban demand via conservation. The demand elasticities with respect to climate variables, housing density, and housing vintage will be used to project future urban water demand in areas of new urban growth in California.
>
> (4) Project future agricultural and urban water demand and supply in California in the absence of climate change, based on economic and demographic scenarios, and projections of land use conversion and patterns of future urban growth in California. This analysis will incorporate results from the econometric analyses conducted in (2) and (3).

(5) Assess how climate variability and change will impact the reliability of water supply—the ex ante probability distributions—for urban and agricultural water agencies in California. This task evaluates alternative models to estimate the impact of climate change on water supply and the factors that determine runoff forecasting and how they relate to climate inputs (e.g., how the amount of water stored in the snowpack affects the accuracy in forecasting).

(6) Assess the economic consequences of the future changes in supply reliability for urban and agricultural water users in California identified in (5) when applied to the future scenarios developed in (4), using the economic loss functions developed in (2) and (3).

The research conducted during the first year has focused on (1), (2), and (3). In addition, this project's research team has started to employ the results of the recent paper in the Proceedings of the National Academy of Sciences dealing with the effects of climate change on California hydrology (Hayhoe 2004) as a preliminary practice for addressing component (5).

This report describes work done in connection with item (3) in the above list, dealing urban water and energy use in California

2. Urban Water Use Data

The study of urban growth and residential water and energy use in California will forecast urban water and energy use under future climate and urban growth scenarios. Because there are many more retail water entities than electricity agencies in California, and because the water utilities are far more open to cooperation (through the California Climate Change Center's membership of the Council on Urban Water Conservation in California), the initial work has focused on urban water use.

2.1 Research Questions

The questions to be addressed about water use include:

1. Do newer residential areas in California use more or less water per capita than existing residential areas? To what extent is this influenced by differences in climate? Or differences in housing density? Or differences in household appliances?
2. If land is converted from agricultural to suburban use, what is the impact on total water use? Do new residential areas use more water per acre than when the land was in agricultural uses?
3. What is the effect of alternative forms of conservation programs on residential water use?
4. How price-elastic is residential water use, both in the short- and long-run?
5. What are the short- and long-run economic costs of reductions in consumer's surplus if there is not sufficient water for residential use?

2.2 Data Collection

Some of these questions can only be answered at the household level, as opposed to the census block group level. For example, whenever there is some form of block rate pricing (i.e., different prices are charged for different amounts of water), it is essential to have individual level data, because any aggregation across households would make it impossible to calculate the price variable correctly, and this biases the estimate of the price coefficient and, hence, the estimate of consumer's surplus.

In addition, in order to account for the effects of housing vintage, housing density, and climate on residential water use, it is important to obtain good variation in these variables across the sample. Therefore, researchers initiated a comprehensive effort to gather household urban water use data from a large variety of utilities around the state. The data collection effort to date has been both intense and successful, particularly considering the difficulty previous researchers have faced in seeking to obtain household level data on water use.

This project's approach was to contact geographically and economically representative urban water providers around the state and asked them to share individual household water consumption data. However, in the interest of protecting their customers' privacy, some providers insisted on aggregating their data to the block group level. The data that researchers received was for time periods of varying lengths depending on the provider's record-keeping capacity and the cost and difficulty to the provider of recovering data from farther in the past.

At this point, this project has data on the water use of over 1.2 million California households, from 15 water agencies around the state. This includes household-level data on over 680,000 individual households, and data aggregated to the block group level for another 534,000 households. The water agencies included in these data are listed in Table 1, together with a summary of the variables covered by these data. The number of households covered is presented in Table 2. The rate structures represented in the data range from a flat rate volumetric charge to as much as a five-tiered increasing block structure.

It should be emphasized that the amount of data that this project has succeeded in obtaining is completely unprecedented in the water economics literature. The existing literature on household-level residential water use involves four or five studies, the largest of which utilizes data on about 1100 individual households, and most of the others utilize data from samples on the order of two or three hundred households. The data set from this project is roughly one thousand times larger than the data sets utilized in the existing literature.

Table 1. Residential water use data collected to date

Water Provider	Level of Aggregation	HH ID	Census Block Groups?	Frequency	Period Covered	Census Data	Water Rates	Conservation Measures	Climate Data
City of Corona	Aggregated to block group	Block group	Yes	Monthly Averages	1998–2003	Still to Download	1998–1999, 3-tiered decreasing block; flat rate from Nov. 1999–2005	Not yet	Yes, through 2004
City of Davis	Household, separated into single- and multi-family	Address	Yes	Bimonthly	1997–2003	Yes	1995–1998 flat rate; 1998: metering and fixed charge for meter plus 1-tier for SF, 2-tier for MF; April 2003 move to 2-tiers for SF; April 2004 increase rates in tiers	Yes	Yes, through 2004
City of Los Altos	Household	Address	Yes	Monthly	10/2002–5/2003	Still to download	Flat rate, fixed charge for meter	Not yet	Yes, through 2004
Los Angeles Department of Water & Power	Household	Block group	Yes	Bimonthly	1987–2004	Yes	Flat rates, then drought rationing, then increasing block (with rate revision)	Yes	Yes
City of Palo Alto	Aggregated to block group	Block group	Yes	Monthly	2002	Still to download	2-tiered increasing block structure	Not yet	Yes, through 2004
City of Riverside	Aggregated to block group	Block group	Yes	Monthly Averages	1999–2003	Still to download	4-tiered increasing block structure, w/ periodic increases	Not yet	Yes, through 2004
City of Santa Barbara	Household, separated into SF and MF + irrigation	Address, plus parcel no.	No	Monthly	2002–2004	Still to download	3-tiered increasing block structure, w/ periodic increases	Not yet	Yes, through 2004
City of Santa Cruz	Household, w/ single- and multi-family designation	Address	No (but easily ascertained through GIS)	Bimonthly	1990–2003	Still to download	meter charge + 2-tier structure in 1993, moved to 3-tier structure in 1995; no rate change 1997–2003	Yes	Yes, through 200

Table 1. (continued)

Water Provider	Level of Aggregation	HH ID	Census Block Groups?	Frequency	Period Covered	Census Data	Water Rates	Conservation Measures	Climate Data
City of Santa Rosa	Household	ID number	Yes	Monthly	10/1998–9/2003	Yes	fixed charge based on meter size, + flat rate volumetric charge	Yes	Yes, through 2004
Cucamonga Valley WD	Aggregated to block group	Block group	Yes	Monthly Averages	2002	Still to download	fixed charge based on meter size, + flat rate volumetric charge	Yes	Yes, through 2004
East Bay MUD	Aggregated to block group	Block group	Yes	Bimonthly	1992–2003	Still to download	fixed charge based on meter size, + multiple-tiered system (increasing tiering from 2 to 3, + differences for MF and SF users)	Almost complete	Yes, through 2004
Eastern Municipal WD	Household	X/Y coordinates	No—problem with the data	Monthly	2002	Still to download	fixed charge based on meter size + flat rate volumetric charge	Yes	Yes, through 2004
El Dorado ID	Household	Address	No (but can be ascertained through GIS)	Bimonthly	2000–6/2004	Still to download	service fee by meter size (and whether pumped) + 3 tiers	Not yet	Yes, through 2004
Irvine Ranch WD	Household	Address	No	Monthly	1994–2003	Still to download	5-tier rate structure with increases during the data coverage period	Yes	Yes, through 2004
Vista ID	Household	Address	Yes	Bimonthly	7/1998–6/2003	Yes	fixed charge based on meter size + flat rate volumetric charge	Not yet	Yes, through 2004

SF=Single Family, MF=multifamily. HH ID=household identification

Table 2. Number of households covered by the water use data

Water Agency	No. Households		No. Block Groups
City of Corona Dept. of Water and Power	31,200	*	78
City of Davis	14,202		
City of Los Altos	12,726		
City of Palo Alto	20,400	*	51
City of Riverside	72,400	*	181
City of Santa Barbara	22,456		
City of Santa Cruz Water Dept.	21,043		
City of Santa Rosa Utilities Dept.	48,003		
Cucamonga Valley WD	19,600	*	49
East Bay MUD	390,800	*	977
Eastern Municipal Water District	65,535		
El Dorado Irrigation District	4,150		
Irvine Ranch WD	65,535		
Los Angeles DWP	400,000		
Vista ID	26,600		
Total	**1,214,650**		**1,336**

Note: * = Household data is aggregated by block group.

2.3 Data Description

The data that have now been collected and are ready for use include the following variables:

(A) Individual household water consumption data or household water consumption data aggregated to the census block group level from participating water providers (see Table 2).

(B) Water and sewer rate data for the period covered by the water use data.

(C) California Irrigation Management Information System (CIMIS) weather station data (temp min, temp max, precipitation) on a monthly basis for 1990–2002 throughout the state.

(D) Water conservation measures in force during the period covered by the water use data, including educational outreach through brochures, information on bills, city/water district web page conservation calculators, direct mailers, washer/toilet/showerhead replacement rebate programs, newsletters, installation of meters, landscape ordinances, low-water using appliances, and more.

(E) Census data includes population, sex by age, households (count, size, type, presence of children), educational attainment, income, housing units, tenure, year structure built, number of rooms, plumbing facilities, value for owner-occupied housing unites, and more.

Of these data, item (A) is what was originally supplied by the water agencies. The information in items (B) and (D) was obtained through a subsequent round of contacts with the agencies. Items (C) and (E) were obtained from the California Department of Water Resources (DWR) and the U.S. Census Bureau, respectively. There is one remaining set of data that needs to be collected:

(F) County assessor's data for the lot sizes in the participating jurisdictions, where these data can be obtained.

2.4 Data Cleaning

As indicated above, this project has now assembled a data set on more than 1.2 million California households, in some cases covering time periods of 15 years or more. From the perspective of data storage alone, this is an immense volume of data, since each individual record (a single household in a single billing period) can contain upwards of 10 or 15 fields; with 6 or 12 billings per years, this number of years, and this number of households, there is a huge volume of data to be checked and cleaned.

In addition, the task of collecting the supplementary information on items (B) and (D) has proved very time consuming.

As a way of prioritizing the econometric analysis, the researchers proceeded as follows. The Los Angeles Department of Water and Power (LADWP) data was the first to be completely cleaned, and this has been the focus of the initial econometric analysis that is reported below. Next, the project focused on completing the data cleaning and processing for the water agencies that use flat-rate pricing, since the econometrics are much more straightforward than those for agencies with increasing block pricing. The data cleaning and processing for the other agencies will be completed last.

3. Data Analysis for Urban Water Use

This project is using the data on residential water use to estimate household-level demand functions for water. When the analysis has been completed, the resulting short- and long-run price elasticities of demand will be used to develop short- and long-run loss functions for shortages in urban water supply in California. The demand elasticities with respect to conservation variables will be used to assess the future potential for reducing urban demand via conservation. In addition, the demand elasticities with respect to climate variables, housing density, and housing vintage will be used to project future urban water demand in areas of new urban growth in California.

The data analysis is still at a preliminary stage. The initial analysis has focused on the data from LADWP and from Santa Rosa. In the case of LADWP, the analysis so far has focused on the 1989–1992 drought; the more recent years' data from LADWP (running through July 2004) are still being processed. The next section presents our analysis of households' responses to water conservation actions initiated by LADWP during the 1989–1992 drought.

Section 3.2 presents some results from an exploratory data analysis of the water use data from Santa Rosa.

3.1 Households' Responses to Water Conservation Programs: The Case of Los Angeles

3.1.1 Introduction

Most of the existing literature dealing with urban water use has addressed the question of price responsiveness using aggregate data on total use by all residential households within a water district (see Hanemann 1998 or Dalhuisen et al. 2003, for a survey). However, such aggregate data are essentially useless if one wants to examine the socioeconomic determinants of water use and water conservation, or the effects of a block rate pricing structure. Furthermore, although the existing literature has devoted considerable attention to analyzing the impact of price as an influence on residential water use, information on the effectiveness of non-price management options such as conservation and information (audit) programs is still relatively sparse; exceptions are Renwick and Archibald (1998) and Renwick and Green (2000). In the latter, the effectiveness of alternative demand-side management policy instruments (such as public information campaigns, subsidies to encourage adoption, and use restrictions) is assessed using agency-level, cross-sectional, monthly time-series data for eight water agencies in California. This study provides useful insights for policy makers regarding the relative effectiveness of price versus non-price policies. However the aggregate nature of the data does not allow the authors to assess how household characteristics influence policy responsiveness.

This project complements Renwick and Green's analysis by using a unique database on Los Angeles water users. This database, which covers water consumption of all households served by the LADWP over the period 1988–1992, provides a unique opportunity to address the question of how households' characteristics influence their responsiveness to various conservation measures, because it allows a broad control of household heterogeneity. The panel form of the data makes it possible to isolate an unobservable time-invariant, household-specific effect, and the large sample size allows the parameters of the water demand function to be made dependent upon households' characteristics, such as lot size and climate zone. This study also differs from Renwick and Green (2000), because consistent panel data techniques are used.

Various conservation measures were implemented by the City of Los Angeles and LADWP during the drought—among them a voluntary conservation program in 1990 and a mandatory conservation program in 1991, which was soon accompanied by a sliding scale of price penalties for failure to comply. The City then subsequently adopted a two-tier increasing block rate structure in 1993, which underwent important modifications in 1995 and has continued in place since then.

The results below indicate that households generally were responsive to the conservation measures, but their responses varied depending on the policy instrument and on their household characteristics. This underscores the importance of controlling for individual heterogeneity.

3.1.2 Background

The Los Angeles Department of Water and Power was established in 1902 to deliver water to City of Los Angeles. Today LADWP serves 670,000 water service connections, of which about 400,000 are residential single-family accounts. Residential consumption represents 64% of the total water supplied by LADWP.

Like other major California urban water agencies, LADWP has long had an active water conservation program. This program included the provision of educational materials for use in schools, community presentations, customer satisfaction surveys for toilet replacements, and a wide range of information distributed through customer bills, advertising, and direct mail. However, starting around 1987, there was a major increase in the nature and level of conservation activities, due to the drought. In 1988, the City adopted a plumbing retrofit ordinance to mandate the installation of conservation devices in all properties and require water-efficient landscaping in new constructions. At the beginning of 1990, Mayor Bradley called for voluntary conservation and threatened to implement mandatory conservation program if this goal was not achieved. At the same time, the ultra-low-flush (ULF) Toilet Rebate Program was inaugurated, followed two years later by the ULF Toilet Distribution Program. The voluntary conservation program continued until March 1, 1991 when a mandatory conservation program was introduced which required all LADWP customers to reduce their water use by at least 10% compared to their usage in the same period in 1986, or otherwise face a series of punitive fines. On May 1, 1991, the conservation requirement was increased to 15%. This continued until the summer of 1992, when the mandatory conservation program was terminated. Note also that bathroom retrofit kits were distributed during the period covered by the drought. The kits included toilet displacement bags that conserve nearly a gallon of water per flush, low-flow showerheads that use less than half the water of standards showerheads, and tablets that detect toilet leaks.

Table 3 shows the average daily consumption per household over the 1988–1992 period. Average daily consumption over the entire year was at its highest in 1989 (473 gallons per day). Households started lowering their consumption (compared to the previous years) from spring 1990, and consumption was at its lowest in 1991. Between 1990 and 1992, households reduced their consumption in all months. Monthly figures (not reported here) show an obvious seasonal pattern: water consumption gradually increased from January (312 gallons per day in average) until July and August, when it reaches its maximum (around 500 gallons per day). The large increase in consumption over the summer signifies the use of water for outdoor purposes.

Table 3. Average daily consumption for each year

Year	1988	1989	1990	1991	1992
Consumption (gallons per household)	460	473	445	347	372

Over the 1988–1992 period, water was charged at a flat rate, which varied with the season: the price was higher during the summer season (June 1 through October 31) and lower in the winter season (November 1 through May 31). Water prices increased gradually over the years, from an average of $1.08 per hundred cubic feet (HCF) in 1988 to $1.46 in 1992 (see Table 4).[1] In the last quarter of 1991, LADWP rewarded consumers for their conservation efforts by canceling the purchased water cost factor, which accounts for the one price decrease during this period.

Table 4. Marginal price, 1988–1992

Year	1988	1989	1990	1991	1992
Consumption ($ per hundred cubic feet)	1.08	1.21	1.35	1.21	1.46

3.1.3 Data and Model Specification

Data Description

For this analysis, the research team started with single-dwelling unit residential customers (i.e., households who are individually metered and billed). They retained only those households who had been billed for the entire period; also they excluded households whose water consumption was not actually read from the meter but was estimated. After these exclusions, a total of 299,339 households were left.

Each household is billed for its water consumption over a period of two months, but the dates of the two-month period vary from one household to another. The LADWP data provide the date of the meter read and the consumption since the last meter read

[1] One HCF per month equals approximately 25 gallons per day. Prices reported in Table 4 have been deflated using the monthly Consumer Price Index for all items, all urban consumers, as measured in Los Angeles-Riverside-Orange County (source: U.S. Department of Labor). January 1994 is chosen as the base month.

(measured in HCF). For each household, LADWP provides the lot size category[2] and the temperature zone (low, medium, and high).

This project's researchers obtained data from the National Weather Service (NWS) in Los Angeles on maximum temperature and total precipitation for each month from January 1988 to December 1992. These climatic data do not vary across households within the data.[3]

Model specification

For now, this project focuses on the conservation measures implemented during the 1987–1992 drought, with the aim of investigating how households' characteristics influence their responses to the various management actions—including rate increases, the voluntary conservation program, and the mandatory conservation program. Because ULF toilet programs were running simultaneously, the estimated responses are likely to be upward biased. However, this research is focused not only in the absolute level of the households' responses, but also in the relative levels of response between one household group and another.

The response to the voluntary and mandatory conservation programs is measured through the estimation of a water demand function that is assumed linear in the parameters. From 1988 to 1992 all residential users were charged a flat rate, which simplifies the estimation of the water demand function. Water demand is commonly specified as a function of water price, climatic conditions, and household characteristics.

To assess the effectiveness of the conservation measures, researchers created two categorical variables: (1) the voluntary program variable (VP), and (2) the mandatory conservation variable (MP). The VP takes the value 1 for periods covered by the voluntary conservation program (from 1 April 1990 to March 1991), and 0 otherwise. The MP takes the value of 1 for periods covered by the mandatory conservation program (from March 1991 to April 1992), and 0 otherwise.

The demand function for water in period *t* for household *i* thus takes the form:

$$CONS_{it} = B_0 + B_1\, PRICE_{it} + B_2\, RAIN_{it} + B_3\, TEMP_{it} + B_4\, VP_t + B_5 MP_t + Z_i\, \gamma + \alpha_i + \varepsilon_{it}$$

where $CONS_{it}$ is average daily water consumption of the household; the Bs and γ are unknown parameters to be estimated; and PRICE, RAIN, TEMP, and Z represent marginal price, rainfall, maximum temperature, and the vector of household's characteristics respectively—the latter being time-invariant. α_i is the unobservable

[2] LADWP distinguishes between five lot size categories. Category 1: less than 7,499 ft^2; Category 2: from 7,500 to 10,999 ft^2; Category 3: from 11,000 to 17,499 ft^2; Category 4: from 17,500 to 43,559 ft^2; Category 5: 43,560 ft^2 and above.

[3] In future work, this project will use the PRISM (Parameter-elevation Regressions on Independent Slopes Model) data, which provides a finer spatial resolution than the National Weather Service data.

household specific effect, and $+\varepsilon_{it}$ is the usual idiosyncratic error term. α_i, assumed time-invariant, will control for household heterogeneity.

Because this project is primarily interested in behavioral responses to price and conservation measures, this analysis allows the parameters B_1, B_2, B_3, B_4, and B_5 to vary across lot size groups and temperature zones (known for each household). In the subsequent analysis, this project's researchers consider as a single group lot sizes 4 and 5 as the share of households having lot sizes greater than 43,560 square feet (lot size 5 is very small). Coefficients of rainfall and temperature are allowed to vary across lot sizes.

Because water use varies sharply by season due to outdoor lawn watering, separate seasonal demand functions are estimated for the high and low seasons.

To prevent endogeneity bias from the correlation of unobservable household-specific effect and model regressors, this analysis uses a "within" estimation procedure (i.e., all the variables are deviated from their time means). This approach relies on the assumption that the demand function for each individual remains the same over the season.

3.1.4 Estimation Results

To simplify the estimation, the research team randomly selected a sub-sample of households. Following the sampling, the study utilized 37,035 households in the high season, and 38,891 households in the low season. As explained before, this approach relies on the assumption that the demand function has remained the same over the entire period. The estimation of the demand function using those years before the implementation of the voluntary and mandatory programs (1988–1990) shows that this assumption is valid on this sample.

This section presents the estimation results based on the demand function fitted using the 1988–1992 data. The "within" estimator is applied to the model where daily consumption and marginal price have been transformed in logarithm.

Tables 5 and 6 display estimated price elasticities across lot sizes and temperature zones, for the high and low season, respectively. These figures measure how water demand varies (in percentage terms) following a 1% increase in marginal price. For example, households having a lot size of 5,000 ft^2 and living in the medium temperature zone are expected to decrease their water consumption by 4.9% following a 10% increase in marginal price in the high season.

Table 5. Estimated price elasticities – High season (significance at the 1% level)

	Temperature Zone		
	Low	**Medium**	**High**
Lot size group			
1–7,499 ft^2	-.36	-.49	-.50
7,500–10,999 ft^2	-.31	-.55	-.49
11,000–17,499 ft^2	-.46	-.60	-.49
17,500 ft^2 and above	-.54	-.52	-.62

Table 6. Estimated price elasticities – Low season (significance at the 1% level)

	Temperature Zone		
	Low	**Medium**	**High**
Lot size group			
1–7,499 ft^2	-.30	-.18	-.14
7,500–10,999 ft^2	-.29	-.15	-.18
11,000–17,499 ft^2	-.32	-.17	-.14
17,500 ft^2 and above	-.30	-.18	-.10

Households are found more responsive to price variation in the high season than in the low season. Price elasticities vary from -0.31 to -0.62 in the high season and from -0.10 to -0.32 in the low season. During high season, households with large lot sizes and living in medium and high temperature zones (and so more likely to have large outdoor water use) are found more responsive to price variation than the other households.

Tables 7 and 8 show the estimated responses to both the voluntary and mandatory conservation programs across lot sizes and temperature zones, for the high and low season, respectively. The figures reported in Tables 7 and 8 are percentage variations of water demand following the application of the conservation programs. For example, households having a lot size of 10,000 square feet and leaving in the high temperature zone are found to have reduced their water consumption by 7.37% in response to the voluntary conservation program in the high season.

Table 7. Estimated responses to conservation measures (%) – High season

	Temperature Zone					
	Voluntary Program			**Mandatory Program**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Lot size group						
1–7,499 ft^2	-7.30 (***)	-6.76 (***)	-5.81 (***)	-27.26 (***)	-26.39 (***)	-28.38 (***)
7,500–10,999 ft^2	-7.88 (***)	-6.38 (***)	-7.37 (***)	-26.81 (***)	-28.30 (***)	-28.18 (***)
11,000–17,499 ft^2	-3.30 (***)	-5.33 (***)	-5.21 (***)	-28.97 (***)	-26.21 (***)	-26.97 (***)
17,500 ft^2 and above	-4.97 (***)	-2.12	-2.73 (***)	-30.41 (***)	-25.05 (***)	-25.36 (***)

(***) indicates significance at the 1% level

Table 8. Estimated responses to conservation measures (%) – Low season

	Temperature Zone					
	Voluntary Program			**Mandatory Program**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Lot size group						
1–7,499 ft^2	-7.51 (***)	-7.21 (***)	-8.20 (***)	-20.68 (***)	-20.56 (***)	-22.39 (***)
7,500–10,999 ft^2	-9.16 (***)	-6.40 (***)	-7.89 (***)	-21.13 (***)	-22.28 (***)	-21.78 (***)
11,000–17,499 ft^2	-8.38 (***)	-5.53 (***)	-5.33 (***)	-20.84 (***)	-19.70 (***)	-23.39 (***)
17,500 ft^2 and above	-10.99 (***)	-0.45	-3.56 (***)	-20.73 (***)	-16.81 (***)	-22.07 (***)

(***) indicates significance at the 1% level

In the high season, households having small lot sizes and living in the low and medium temperature zones responded more to the voluntary conservation program. These households reduced their consumption by 6% to 8%, while the households in the other groups reduce their consumption 5% or less—and in some cases failed to reduce their consumption (the voluntary program is non-significant for households having the largest lot sizes and living in the medium temperature zone). All households significantly responded to the mandatory conservation programs.

The reduction in water use varies from 25% to 30% in the high season, and from 17% to 23% in the low season. The relative decrease in water use is quite similar across groups.

To check for equal responses across groups, researchers performed Wald tests. Researchers first tested the null hypothesis that price elasticities and responses to the conservation programs are equal across all households groups (i.e., across both lot sizes and temperature zones). The null hypothesis was rejected at the 1% level of significance in all three cases for each season. The team then performed separate Wald tests across lot sizes and across temperature zones, to test whether households having comparable lot sizes react the same regardless of the temperature zone, and whether households living in a particular temperature zone have equal responses regardless of lot size.

In general, the responses to price variation and conservation measures were found to be significantly different between household groups. However, Wald tests showed that, for a given lot size group, households had the same response to the voluntary program during the high season, regardless of the temperature zone.

It should also be noted that the estimated coefficients of rainfall and maximum temperature, allowed to vary across lot size categories, are significant in every case. As expected, higher rainfall and lower maximum temperature decrease average water consumption. The responses to variation in rainfall and temperature are significantly different from one lot size group to another.

3.1.5 Los Angeles Case Study Summary

This report presents a comprehensive analysis of household responses to water conservation programs. Using a large and representative sample of households, the research team found that household responses to conservation measures vary with respect to their own characteristics—in particular the size of their lot and the temperature zone. Households are found more responsive to price variation in the high season than in the low season. Price elasticities vary from -0.31 to -0.62 in the high season and from -0.10 to -0.32 in the low season. During high season, households that are more likely to have large outdoor water use are found more responsive to price variation than the other households. In the high season, households having small lot sizes and living in the low and medium temperature zones responded more to the voluntary conservation program. All households significantly responded to the mandatory conservation programs. These results are of high importance for water management and planning, because they show that conservation programs generally have a different impact across the population of households.

3.2 The Case of Santa Rosa

This section presents an initial tabular analysis of households in Santa Rosa, based on a randomly selected sample of 10% of all households served by the city. The sample contains 4,801 households, for whom consumption has been followed monthly from October 1998 through September 2003. Over the period, the mean consumption is 14,000 gallons per month, varying from a minimum of 1,000 to a maximum of 5,259,000 gallons per month. Such a large consumption level probably corresponds to a multi-family unit. Because the city records do not permit researchers to distinguish between single-family and multi-family units, they trimmed the data and removed the 5% highest observed consumptions. Monthly consumption (in the trimmed distribution) varies from 1,000 to 33,000 gallons, with an average of 9,000 gallons per month.

The distribution (after trimming) of monthly consumption is presented in Figure 1 below. This figure distinguishes between high (from June 1 to October 31) and low (from November 1 to May 31) seasons.

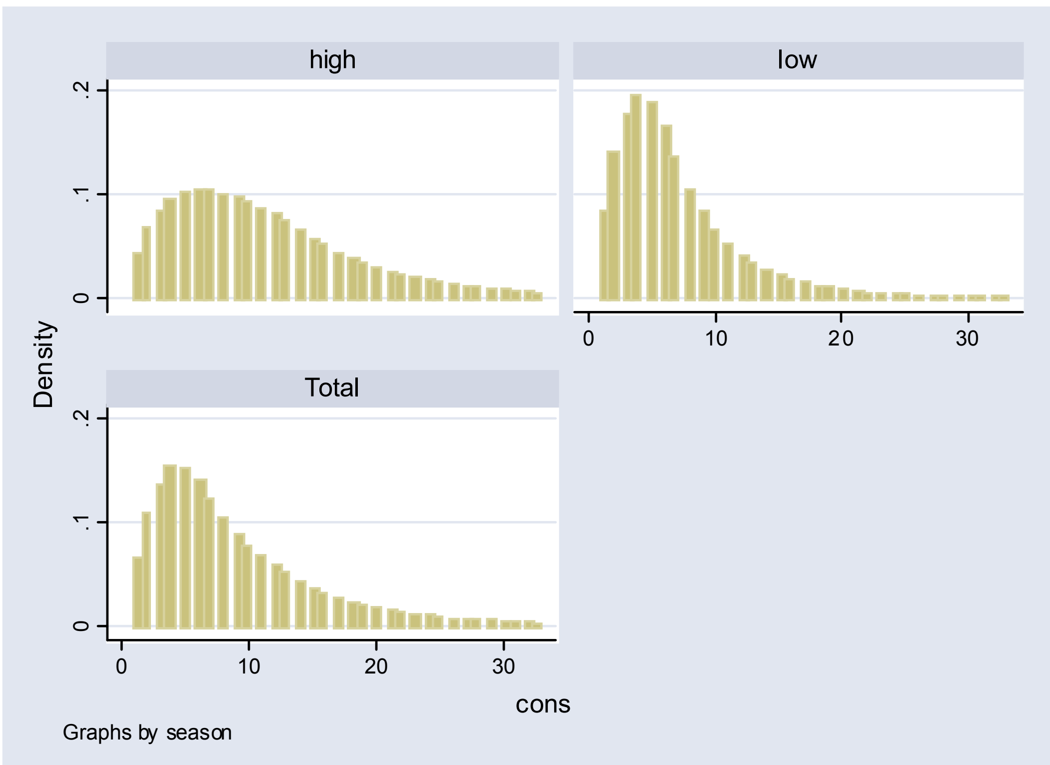

Figure 1. Distribution of monthly urban water consumption (in 1,000 gallons)

The shape of the water consumption distribution is different between high and low seasons. The flatter shape of the distribution in the high season illustrates the increase in water use at this period.

Some descriptive statistics made at the block level follow. Note that consumption is averaged over time for each census block. The total number of blocks is 130.

The graphs in Figure 2 show a positive relationship between median income in the block (horizontal axis) and monthly consumption (vertical axis), especially in the high season. High income blocks commonly have bigger lots where outdoor water use is significant during the dry season.

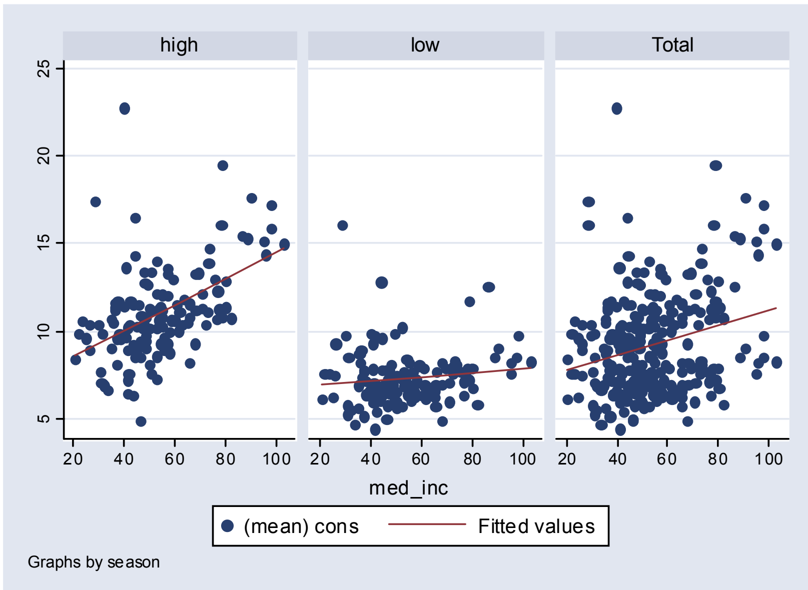

Figure 2. Plot of median income (US$1,000) and monthly consumption (1,000 gallons), for high and low seasons, and overall

The graphs in Figure 3 show a steep increasing relationship between median value of the house and monthly consumption. The slope is steeper in the high season.

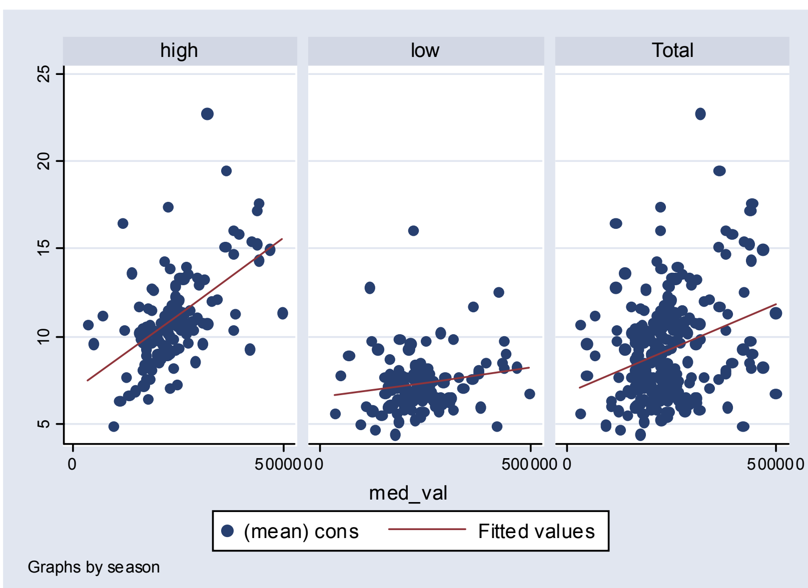

Figure 3. Plot of median value of the house (in US $) and monthly consumption (1,000 gallons), for high and low season, and overall

The graphs in Figure 4 illustrate that blocks with newly built homes have a (slightly) higher monthly consumption, especially in the high season.

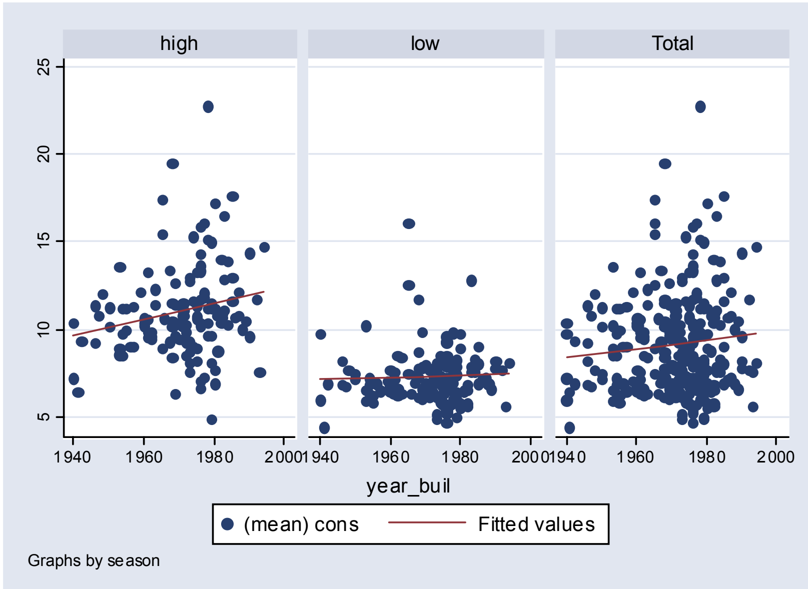

Figure 4. Plot of median year of structure built and monthly consumption (1,000 gallons), for high and low season, and overall

The next series of graphs looks more specifically at the relationship between housing vintages and monthly consumption, across seasons. In those blocks where there is a higher share of houses built after 1999, the monthly consumption is higher in average (very few points), as shown in Figure 5.

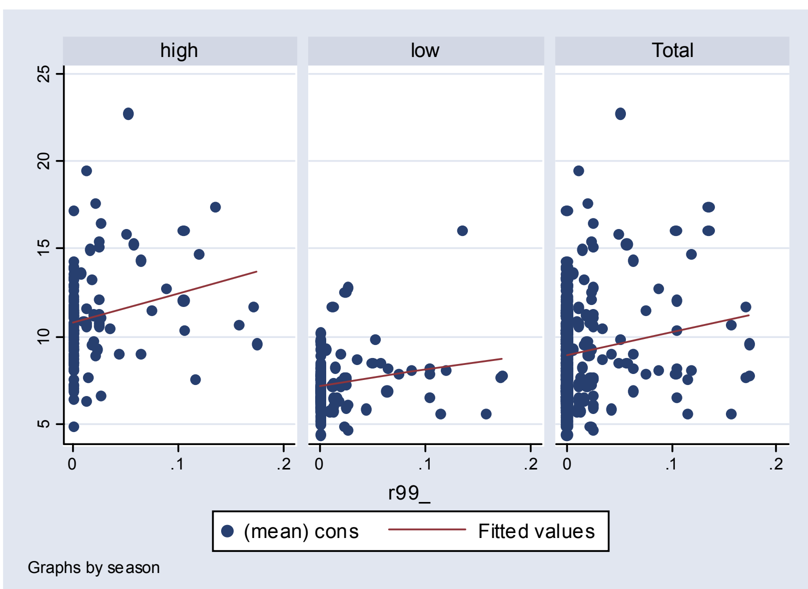

Figure 5. Plot of share of houses built after 1999 and monthly consumption (1,000 gallons), for high and low season, and overall

Figure 6 illustrates a positive relationship between the share of houses built between 1995 and 1998 and monthly consumption, especially in the high season.

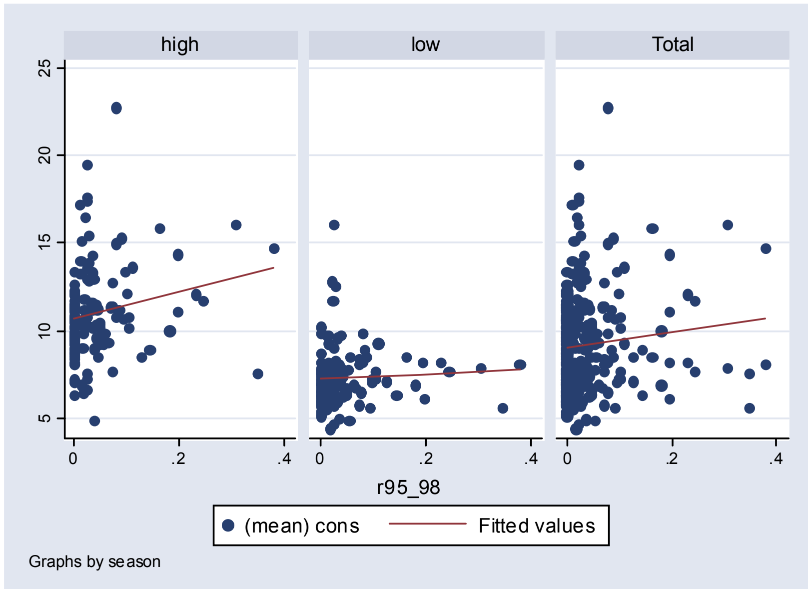

Figure 6. Plot of share of houses built between 1995 and 1998 and monthly consumption (1,000 gallons), for high and low season, and overall

The graphs in Figure 7 do not show any relationship between the share of houses built between 1990 and 1994, and monthly consumption.

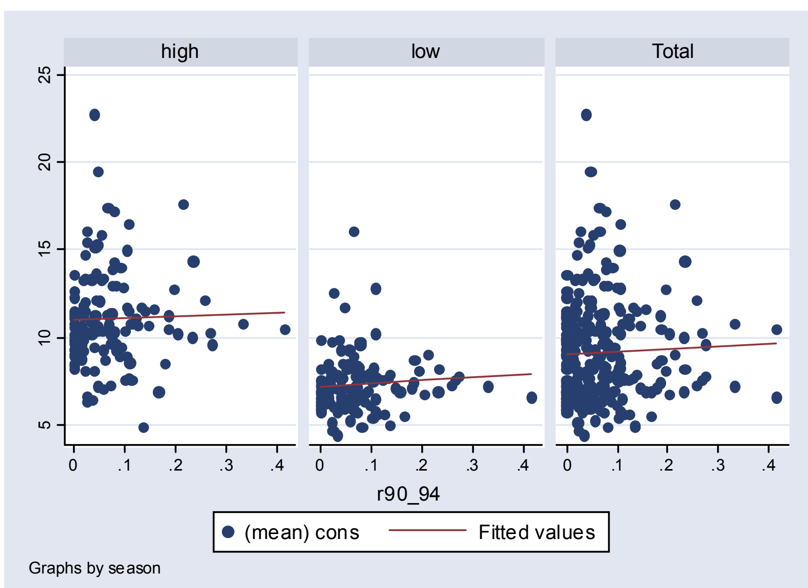

Figure 7. Plot of share of houses built between 1990 and 1994 and monthly consumption (1,000 gallons), for high and low season, and overall

The graphs in Figure 8 show a slightly increasing relationship between the share of houses built between 1980 and 1989 and monthly consumption.

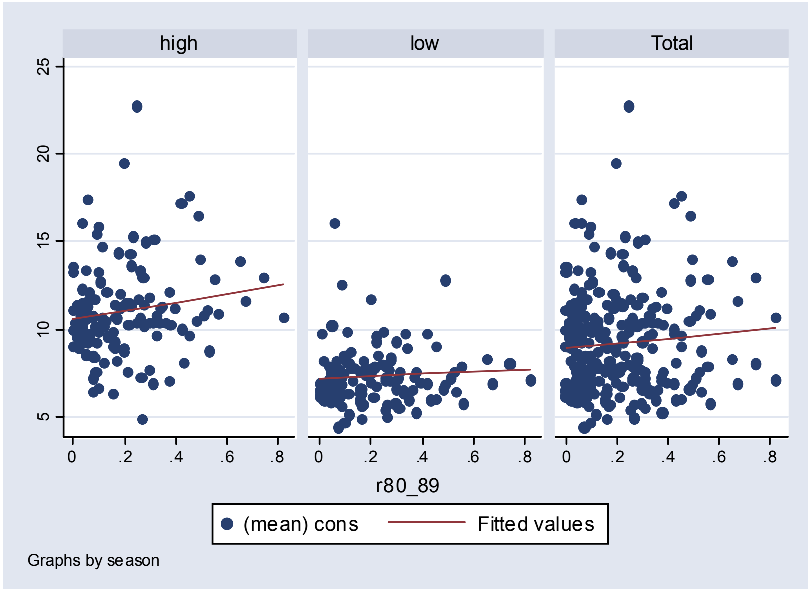

Figure 8. Plot of share of houses built between 1980 and 1989 and monthly consumption (1,000 gallons), for high and low season, and overall

This graphs in figures 9 through 13 indicate that blocks with a higher share of houses built before 1979 have a lower monthly consumption.

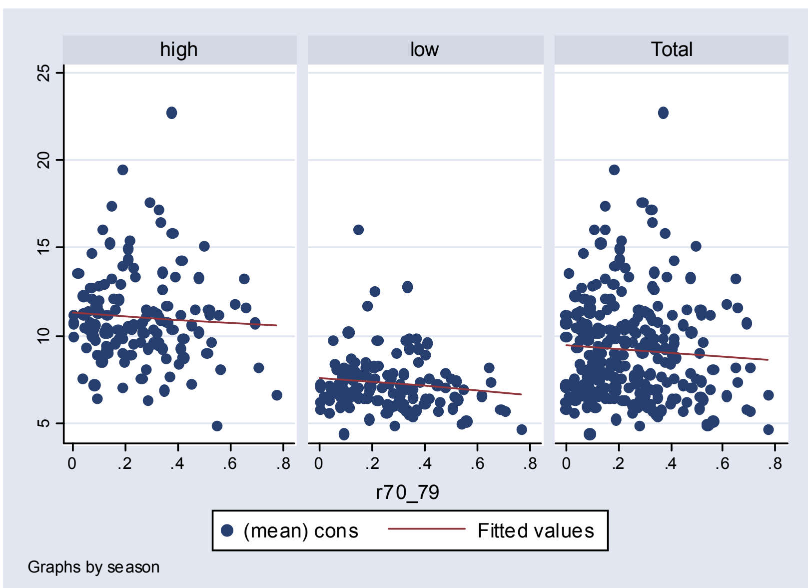

Figure 9. Plot of share of houses built between 1970 and 1979 and monthly consumption (1,000 gallons), for high and low season, and overall

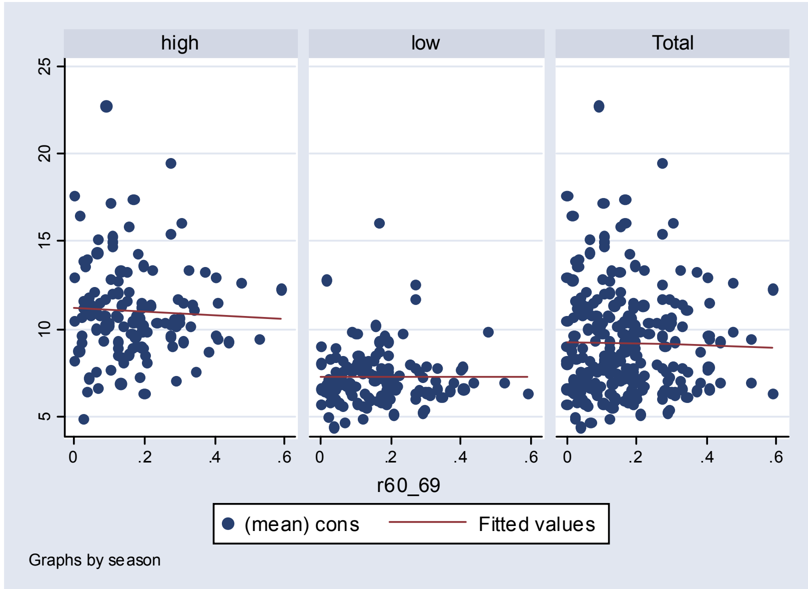

Figure 10. Plot of share of houses built between 1960 and 1969 and monthly consumption (1,000 gallons), for high and low season, and overall

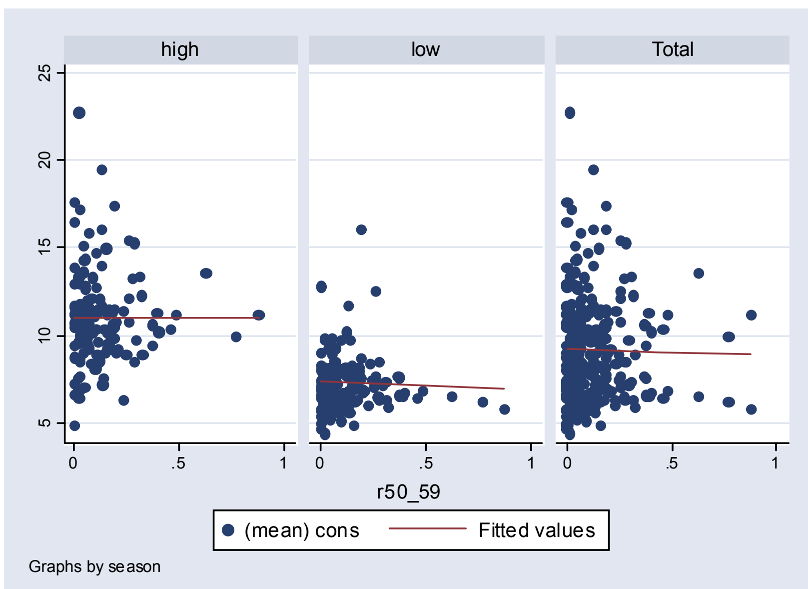

Figure 11. Plot of share of houses built between 1950 and 1959 and monthly consumption (1,000 gallons), for high and low season, and overall

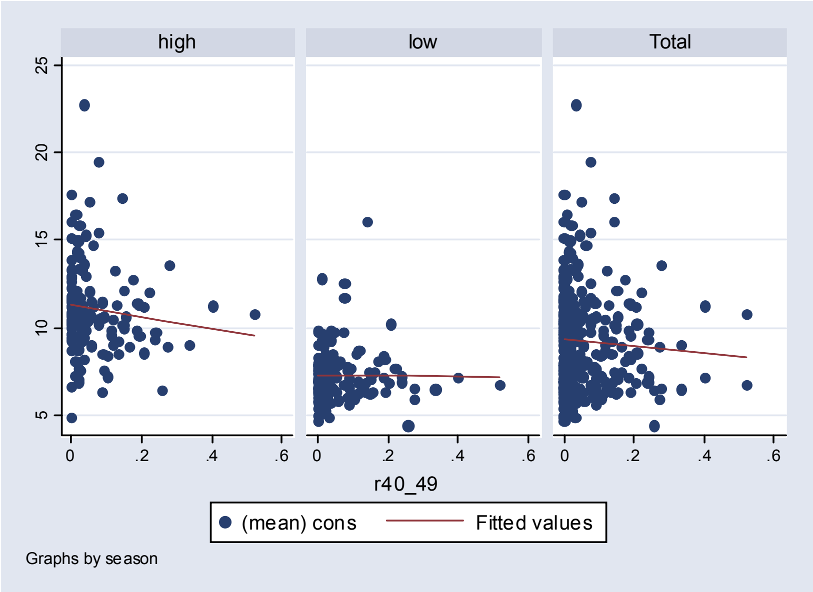

Figure 12. Plot of share of houses built between 1940 and 1949 and monthly consumption (1,000 gallons), for high and low season, and overall

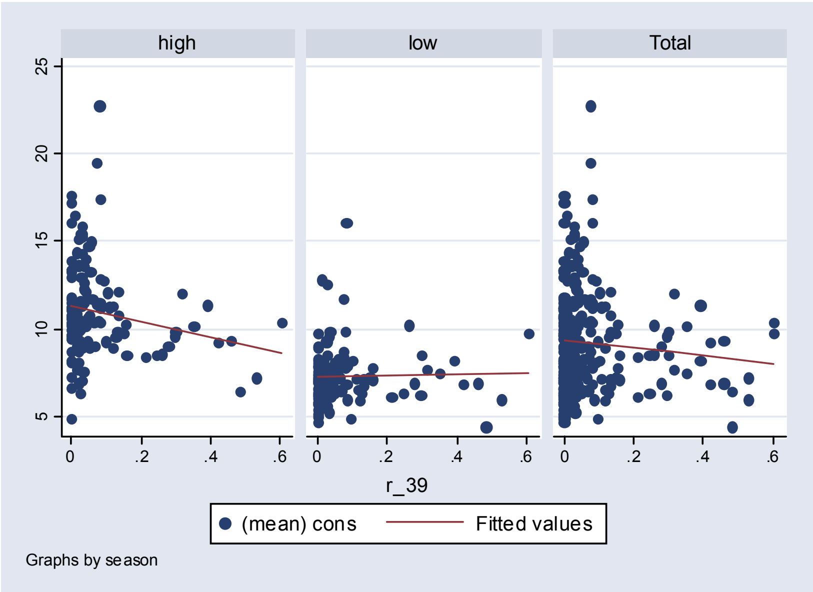

Figure 13. Plot of share of houses built before 1939 and monthly consumption, (1,000 gallons) for high and low season, and overall

Tables 9 and 10 show correlation coefficients, for low and high seasons, and overall.

Table 9. Correlation coefficients – Overall sample

	Monthly consumption	Median income	Median year built	Median value of the house
Monthly consumption	1.0000			
Median income	0.2589***	1.0000		
Median year built	0.1059*	0.3031***	1.0000	
Median value of the house	0.2995***	0.7272***	0.0529	1.0000
Share of houses built after 1999	0.1620***	0.0080	0.3321***	-0.0365
Between 1995 and 1998	0.1043*	0.1910***	0.3987***	0.1603***
Between 1990 and 1994	0.0363	0.1900***	0.5280***	-0.0558
Between 1980 and 1989	0.0865	0.2906***	0.6317***	0.0692
Between 1970 and 1979	-0.0648	-0.0181	0.3200***	-0.0719
Between 1960 and 1969	-0.0226	-0.1202*	-0.1701***	-0.0170
Between 1950 and 1959	-0.0132	-0.0585	-0.5284***	0.0081
Between 1940 and 1943	-0.0555	-0.2174***	-0.7105***	-0.0549
Before 1939	-0.0853	-0.2769***	-0.6998***	0.0059

Note: ***, * indicates significance at the 1% and 10% level, respectively.

Table 10. Correlation coefficients – By season

	Overall	High season	Low season
Monthly consumption	1.0000	1.0000	1.0000
Median income	0.2589***	0.4841***	0.1254
Median year built	0.1059*	0.2045**	0.0402
Median value of the house	0.2995***	0.5422***	0.1751**
Share of houses built after 1999	0.1620***	0.2255***	0.2092**
Between 1995 and 1998	0.1043*	0.1888**	0.0611
Between 1990 and 1994	0.0363	0.0275	0.0857
Between 1980 and 1989	0.0865	0.1501*	0.0615
Between 1970 and 1979	-0.0648	-0.0601	-0.1343
Between 1960 and 1969	-0.0226	-0.0488	0.0003
Between 1950 and 1959	-0.0132	0.0001	-0.0483
Between 1940 and 1943	-0.0555	-0.1132	-0.0109
Before 1939	-0.0853	-0.1952**	0.0190

Note: ***, **, * indicates significance at the 1%, 5%, and 10% level, respectively.

3.2.1 Santa Rosa Case Study Summary

Correlation coefficients confirm what was shown by the graphs. The positive correlation between median income and monthly consumption is highly significant in the high season but not significant in the low season. The higher the median value of the house, the higher the average monthly consumption. There is a significant positive correlation between the median year of houses built and monthly consumption in the high season; this correlation is non-significant in the low season. Overall, researchers observed a positive correlation between the share of houses built after 1980 and monthly consumption, and a negative correlation between the share of houses built before 1980 and monthly consumption. However the blocks in which there is a larger share of recent houses are blocks with high income households (see the positive and significant correlation between median income and share of houses built after 1980), while the blocks in which there is a larger share of old houses are the blocks where low-income households live. So the positive correlation observed between the share of recent houses and monthly consumption may be because the recently built houses were built by high-income households.

Finally, Table 11 presents some statistics for the four quartiles of the consumption distribution. The fist quartile gathers the blocks where monthly consumption is the lowest. These figures confirm the discussion above.

Table 11. Consumption distribution for low and high season, by quartile

	Low Season				High Season			
	First quartile	Second quartile	Third quartile	Fourth quartile	First quartile	Second quartile	Third quartile	Fourth quartile
Number of blocks	33	32	33	32	33	32	33	32
Average monthly consumption (1,000 gallons)	5.71	6.66	7.45	9.29	8.16	10.12	11.27	14.68
Average year built	1971.7	1969.0	1973.0	1973.5	1969.7	1969.1	1972.6	1975.1
Average income (US $)	55,928	62,746	58,779	70,032	53,751	51,988	63,339	75,583
Average house value (US $)	244,804	270,867	239,521	341,775	214,915	218,881	276,937	343,028
Share of houses built after 1999	0.02	0.01	0.02	0.04	0.01	0.02	0.03	0.03
Between 1995 and 1998	0.04	0.03	0.05	0.09	0.04	0.03	0.06	0.08
Between 1990 and 1994	0.06	0.06	0.11	0.09	0.06	0.09	0.07	0.10
Between 1980 and 1989	0.19	0.20	0.23	0.20	0.17	0.18	0.22	0.24
Between 1970 and 1979	0.30	0.24	0.22	0.23	0.29	0.21	0.27	0.22
Between 1960 and 1969	0.16	0.18	0.15	0.13	0.18	0.19	0.13	0.14
Between 1950 and 1959	0.11	0.15	0.11	0.09	0.10	0.14	0.12	0.11
Between 1940 and 1943	0.05	0.07	0.06	0.05	0.07	0.07	0.06	0.04
Before 1939	0.06	0.06	0.06	0.07	0.08	0.08	0.05	0.03

4. Urban Growth/Density Model

This project is continuing work to model the conversion of land in California from non-urban to urban use, using the California Urban and Landscape Analysis Model (CURLA), which serves as the basis for predicting the location of future urban growth. An important refinement of this work is to predict the density of development as well as location. The forecasts of urban growth will be combined with the predictions of per capita urban water use as function of location and housing density, vintage, and style, to generate baseline forecasts of future urban water use in California for use in climate change scenarios. The prediction of new housing density is an important component of the current research, enabling more accurate forecasts of urban water demand than ever before.

The California Urban and Landscape Analysis Model was constructed as follows. The research team began by calibrating a ten-category statistical model of changes in density category between 1990 and 2000 for all private lands in California as represented by one-hectare grid-cells. The calibrated model parameters were then used with contemporary spatial data to generate a composite density transition layer identifying the most probable terminal density for each grid-cell. Operated in simulation mode, these probabilities can be “dialed-up” or “dialed-down” by users interesting in increasing or decreasing the relative importance of the various factors that explain changes in density.

Finally, the model allocates a projected increment of population growth to all non-precluded grid-cells in a given region, county, or user-specified study area, in order of estimated density probability. The result of all these steps is a map of projected future densities at all locations associated with a given increment of population growth.

4.1 Urban Growth Model Calibration

Before a model can be reliably used for forecasting or simulation, it must be calibrated. With non-spatial models, this process usually involves fitting a line or curve to historical data. With spatial data, it involves developing equations and estimating parameters that are sensitive to locational and non-locational influences. In this case, the model being calibrated (the CURLA model) relates changes in the density category of particular grid-cells between 1990 and 2000 to their various physical, locational, and administrative characteristics. As with all statistical models, the estimated parameters describe the relationships between a set of independent or explanatory variables and a dependent variable.

$$\text{Prob [Change to a different density category between 1990 and } 2000_I] = f(X1_I, X2_I, \ldots\ldots Xn_I)$$

The dependent variable in this case is the change in grid-cell density category between 1990 and 2000. Ten categories of change are identified:

1. no change in density category between 1990 and 2000
2. increase to .005–.05 dwelling units per acre category
3. increase in density to .05–.1 dwelling units per acre category
4. increase in density to .1–.5 dwelling units per acre category
5. increase to .5–2 dwelling units per acre category
6. increase to 2–4 dwelling units per acre category
7. increase to 4–8 dwelling units per acre category
8. increase to 8–16 dwelling units per acre category
9. increase to 16–48 dwelling units per acre category
10. increase to more than 48 dwelling units per acre category

Note that all “no changes” are treated the same way, regardless of the initial density category.

5. Data on Residential Electricity Use

With regard to residential energy use, it may not be possible to obtain data at the household level comparable to the water use data obtained for this project. At this time, this project's researchers have collected three types of electricity information, (1) Energy Commission county data, (2) Pacific Gas and Electric (PG&E) service area data, and (3) Residential Appliance Saturation Survey (RASS) survey data.

5.1 California Energy Commission Data

The Energy Commission provided 1980–2000 data broken down monthly, by utility, and SIC code. The quality of these data depends on which region of the state it is from. Turlock and Modesto have their own utilities, so these areas can be looked at on a monthly time step for the time period 1980–2000. For the regions served by PG&E, there are monthly breakdowns for the 2001–2002 period, and annual data for the 1983–2001 period.

5.2 PG&E Data

The energy use data from PG&E is broken out by service area and Distribution Planning Area (DPA). The data includes electricity usage by DPA and by PG&E schedule (type of usage). Thus, the research team will be able to separate out which schedules are used mainly for pumping.

5.3 RASS Survey Data

The California Energy Commission administers the Residential Appliance Saturation Survey (RASS). The Residential Appliance Saturation Survey is sponsored by five participating utilities: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), Southern California Gas Company (SoCalGas), Los Angeles Department of Water and Power (LADWP), and San Diego Gas & Electric (SDG&E).

The RASS includes four main categories of data:

1. Saturation of residential appliances
2. Characteristics of residential population
3. Characteristics of dwelling units
4. Patterns of electricity and natural gas consumption

These RASS data include 21,920 customer responses to questions about these data. The responses are confidential, and information about the responses is broken out by zip code.

6. Conclusions, Recommendations, and Benefits to California

This study offers preliminary results of our analysis of the impacts of price and conservation programs on water consumption in selected urban areas in California. Our work is currently being augmented by pooling data across cities, as well as conducting similar single-city analysis with other cities' consumption data.

Los Angeles households are found more responsive to price variation in the high season than in the low season. Price elasticities vary from -0.31 to -0.62 in the high season and from -0.10 to -0.32 in the low season. During high season, households with large lot sizes and living in medium and high temperature zones (and so more likely to have large outdoor water use) are found more responsive to price variation than the other households. Los Angeles households are also generally responsive to conservation measures, but the size of the response varies depending on the policy instrument and on household characteristics.

The Santa Rosa patterns suggest that the size of new houses and/or their lot sizes, and the sheer associated quantity of fixtures in the new housing, despite conservation measures and price structures, are generating more water consumption per household. This increasing demand, with simultaneously limited water supply, has important implications for California’s water policy.

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